XVIII. *Experiments on the Effect of various Subſtances in lowering the Point of Congelation in Water.* *By* Charles Blagden, *M. D. Sec. R. S. and F. A. S.*

Read April 24, 1788.

THE experiments which were neceſſary, in order to determine what effect the admixture of various ſubſtances would produce upon the property of water to be cooled below the freezing point*, naturally led me to a more particular conſideration of the power of ſuch admixtures in making water require a greater degree of cold before it congeals. Many curious queſtions occurred on this ſubject, which could only be anſwered by freſh experiments. Theſe were made nearly in the ſame manner as the preceding; that is, the liquor, whoſe freezing point I meant to try, was put into a glaſs tumbler, to the height of two or three inches above the bottom, and the tumbler was then immerſed in a frigorific mixture of common ſalt and ice or ſnow. As the object was ſeldom to cool the liquor as much as poſſible below its freezing point, the operation required no particular care, but the frigorific mixture was commonly permitted to act with its full force: wherefore, ſome parts of the liquor were often much colder than others; and particularly, near the top, a thermometer would uſually ſtand ſeveral degrees higher than toward the bottom, becauſe the ſurface was conſtantly warmed by the air of the room.

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* See p. 125. of this Volume.

My firſt object of inveſtigation was the ratio according to which equal additions of the ſame ſubſtance depreſs the freezing point. I began with common ſalt; and in order to avoid as much as poſſible a fallacy in the experiments, becauſe the ordinary ſalt is never pure, and often not perfectly neutral, I choſe ſome clean ſalt, in fair cryſtals, which is ſold in London under the name of Borrowſtounneſs pure ſalt. This ſalt I diſſolved in diſtilled water, in various proportions, and found the correſponding points of congelation to be as is expreſſed in the annexed table; where the firſt column indicates the number of parts and decimals of water to one part of the ſalt, and the ſecond column ſhews the freezing point found by the experiment. It appeared clearly, on comparing the proportions of water to ſalt, with the correſponding number of degrees which the freezing point was reduced below 32°, that the effect of the ſalt was nearly in a ſimple ratio; namely, that if the addition of a *tenth* part of ſalt to the water ſunk the freezing point about 11 degrees, or to 21°, it would be depreſſed double that quantity, or to 10° nearly, when a *fifth* part of ſalt was diſſolved in the water. To ſhew, therefore, how far this ſimple proportion is exact, I have added a third column to the table, which is made by ſelecting the loweſt freezing point that was obtained without ambiguity in the experiment, and calculating, by a ſimple inverſe proportion, what all the other points ſhould have been according to that ratio. Thus when a fourth part of its weight of common ſalt was diſſolved in water, I found the freezing point of the liquor to be 4°; therefore, to determine what it ſhould be when only $\frac{1}{32}$ part of ſalt was added to the water, the formula is 32 : 4 :: 28 (the number of degrees that the point 4° is below the freezing point of pure water) : 3½; which ſubtracted from 32° gives

28°½ for the freezing point of that ſolution. All the reſt of the third column of the table is found in the ſame manner, and with very little trouble, becauſe 4 × 28 = 112 is a conſtant number, which being divided by the numbers of the firſt column, the quotient is the number of degrees ſought. In all the experiments, none but diſtilled water was employed.

Common Salt.

Proportion of water to the ſalt.	Freezing point by the experiment.	Freezing point by calculation.
32 : 1	29°	28°½
32 : 1	28 +	28½
24 : 1	27½	27⅓
16 : 1	25¼	25
10 : 1	21½	20¾
7,8 : 1	18½	17⅔
6,2 : 1	13½	14
5 : 1	9½	9½
5,5 : 1	7⅕	7
4 : 1	4	4

The third column is calculated from the laſt experiment, in which the freezing point of a ſolution of one part of ſalt in four of water proved to be +4°.

The numbers in the third column of the table come ſo near to thoſe in the ſecond, that moſt likely the ſmall differences between them ought to be aſcribed to errors in the experiment; whence we ſhould conclude, that the ſalt lowers the freezing point in the ſimple inverſe ratio of the proportion which the water bears to it in the ſolution.

In the courſe of the experiments made with the different ſolutions of this ſalt, ſome phænomena occurred which deſerve further attention.

1. This ſolution was in one inſtance cooled 8½, and in ſeveral 5 or 6 degrees, below its freezing point; but in general it

ſhot rather more readily than ſome other ſolutions; which I aſcribed, from the analogy of my former experiments, to its leſs tranſparency. Though the common ſalt did not form a turbid ſolution, yet there was ſomething of a greyiſh caſt, much like what is produced by the mixture of a ſmall portion of clay with pure water; and the caution in conducting the operation, neceſſary to make ſolutions of this ſalt cool a certain number of degrees below their freezing point, ſeemed to be nearly the ſame as would be required with water equally tinged by means of clay.

2. When the ſolution was very ſtrong, nearly ſaturated with the ſalt, cooling it tended ſomewhat to leſſen this greyiſh caſt, to render it rather more limpid: as was particularly the caſe in a ſaturated ſolution which I cooled to 0°. I ſuſpect this effect takes place when the ſolution begins to expand with the cold.

3. In the ſtrong ſolutions, when the proportion of ſalt was as much as one-fifth, before the real congelation came on which reduced the whole to one temperature, ſeveral ſmall ſtellated cryſtals formed in the liquor, which increaſed very ſlowly. Theſe were real ice of the ſalt water; but the cold being in this caſe very little below the freezing point of the ſolution, there was little power to make them ſpread; and ſometimes, when this occurred, I believe, part of the ſolution toward the top was rather above than below the freezing point. Similar phænomena were obſerved, and in a ſtill more remarkable manner, in the ſolutions of ſome other ſalts, always when they were very ſtrong: and it may be given as a general fact, that in ſolutions approaching to ſaturation, though the formation of one glacial cryſtal does, as in pure water, tend to make the whole freeze and come up to an uniform temperature, yet the ſhooting goes on much more ſlowly, as if the

ſalt oppoſed ſome reſiſtance, or at leaſt proved an impediment, to the progreſs of the cryſtallization. By ſtirring the ſolution, however, when theſe ſtellated cryſtals once began to form, they quickly increaſed in bulk, or became more numerous, and the liquor aſſumed its freezing temperature.

4. This ſalt with ſnow, in the manner of frigorific mixtures, produced a cold of − 4°.

The next ſalt which I tried for its effect in lowering the freezing point of water, was nitre. It was part of a large compound cryſtal, or bundle of cryſtals, apparently very pure, ſuch as is uſed in manufacturing the beſt gunpowder. This being mixed with the diſtilled water, in different proportions, the ſolutions froze according to the following table.

Nitre.

Proportion of water to the ſalt.	Freezing point by the experiment.	Freezing point by calculation.
	°	°
32 : 1	30½.	30½
24 : 1	30	30
16 : 1	28¾	29
10 : 1	27	27¼
8 : 1	26	26
7,9 : 1	26½	ſalt depoſited
7 : 1	26½	ſalt depoſited
6,85 : 1	27	much ſalt depoſited.

The third column is calculated from the fifth experiment, in which the freezing point of a ſolution of one part of ſalt in eight of water proved to be 26°.

Nitre is well known to differ from common ſalt in being much more ſoluble in warm than in cold water. Hence it would be nothing remarkable, that the ſolutions being made in water above the freezing point, ſome of the ſalt ſhould, when they exceeded a certain ſtrength, be depoſited before they began to freeze. But a further queſtion occurred here, whether, when a ſolution was cooled below its freezing point, the ſalt would ſtill continue to be depoſited; or whether it would not have parted with all the ſalt it was obliged to let go by the time it came to the degree at which it was to freeze, and would retain the remainder notwithſtanding any ſubſequent cooling. To determine this, I noticed carefully the quantities of ſalt depoſited at the bottom of the tumbler, in compariſon with the cold of the ſolution as ſhewn by the immerſed thermometer; and I found, that in ſome caſes (for inſtance, when the ſalt was to the water only as 1 : 10) the depoſition did not begin till after the ſolution had paſſed its freezing point; and that, when it began earlier, ſtill there was no ſtop at the freezing point, but the quantity continued augmenting as the cold of the ſolution proceeded, and, as far as I could judge, rather in an increaſing ratio. Thus when the ſaturated ſolution was cooled 8 or 10 degrees below its freezing point, which often happened, the collection of nitre at the bottom was very great; and in this manner I could render a ſaturated ſolution of nitre no longer ſaturated when it came to freeze, the deficiency being ſometimes ſo great as to raiſe the point of congelation a degree or more. Hence was aſcertained the unexpected fact, that the lower ſuch ſolutions are cooled, the higher is their freezing point.

The nitre depoſited by the ſolution as it cooled, formed, if the veſſel remained at reſt, ſmall but very white and compact priſmatic or needle-like cryſtals, of conſiderable length, pointing different ways, and at laſt curiouſly interwoven with one another. But if theſe were broken down, or the ſolution was ſtirred with any force, the remaining nitre depoſited itſelf in ſuch minute cryſtals as to have much the appearance of a powder; I ſuppoſe from the deſtruction of the regular ſurfaces upon which it would otherwiſe have continued to form.

Frequently, in the ſtronger ſolutions, there appeared near the bottom and ſide of the tumbler many elegant ſtellated cryſtals, perhaps a quarter of an inch in diameter, all ſeparate, but ſometimes crowding very cloſe upon one another, ſo as to exhibit a ſpectacle of much beauty.

The ice of ſolutions of nitre, eſpecially when it began to thaw, was very different from common ice, having a ſoft woolly appearance, as if of a more tender and looſe texture. Something of the ſame kind was obſervable in the ice of all the other ſolutions, ſufficiently diſtinguiſhing it from any that can be formed of pure water.

All the ſolutions of nitre were remarkably limpid, having no tendency to an opaque or turbid caſt; and accordingly they were very eaſily cooled below the freezing point, and could not but with difficulty be made to ſhoot till they had paſſed it many degrees. In two inſtances they cooled more than 10 degrees; namely, a ſolution of one part of nitre in 24 of water cooled ſlowly to 19°½, and then ſhooting, the thermometer came up to 30°; and another ſolution, in which the nitre was to the water as 1 : 10, cooled rather below 16°, and having produced ſome ſtellated cryſtals, roſe, when the perfect congelation took place, up to 27°.

As, when pure water is cooled below its freezing point, the leaſt particle of ice or ſnow brought into contact with it cauſes an inſtant congelation, I was curious to know whether the ſame effect would be produced when ſalts were diſſolved in the water. Therefore, having one of theſe nitrous ſolutions, whoſe proportions were 8 : 1, I cooled it to 24°, about two degrees below its freezing point, and then, no ſalt being depoſited, I put into it a ſmall bit of ice. The effect of this was not inſtantaneous, as in pure water, though ultimately the ſame; the bit of ice gradually enlarged, and when it was ſtirred about in the liquor, a number of ſtar-like cryſtals formed, which being ſcattered through it ſoon brought it to an uniform temperature of 26°. This ſame ſolution, when cooled in a preceding experiment to 18°, had its freezing point at 27°, from the quantity of nitre that had been depoſited. In all ſolutions, therefore, of ſuch ſalts as are much more ſoluble in hot than in cold water, if it be deſired to find their freezing point when they are loaded with as much of the ſalt as the water can contain at that temperature, the moſt effectual method is to oblige them to ſhoot, as ſoon as they can be made to do ſo, by putting in a ſmall bit of ice or ſnow; for thus the fallacy which might otherwiſe ariſe from the depoſition of ſome of the ſalt will be avoided.

A doubt having been ſuggeſted, whether the contact of a cryſtal of ſalt might not alſo bring on the congelation, that experiment was tried, but it produced no effect. Indeed, the formation of ſaline cryſtals in theſe experiments, the liquor ſtill remaining fluid, was a ſufficient proof to the contrary.

There is another phænomenon which I thought took place in ſolutions of nitre and ſome other ſalts, but could not abſolutely ſatisfy myſelf concerning it; namely, that the depoſition of ſome ſalt haſtened that of the remainder. For inſtance, ſuppoſe that a ſolution of nitre in the proportion of 1 : 8, would retain the whole of its ſalt at its freezing point of 26°; then, if another ſolution were made much ſtronger, it would begin to depoſit its ſalt before it came to 26°; and when cooled to

26°, it would not have juſt loſt the difference between the proportions of 6 : 1 and 8 : 1, but would have depoſited more of the ſalt, ſo that now at 26° it would contain perhaps only a tenth of nitre; as if the formation or exiſtence of ſome cryſtals in the ſolution facilitated the ſeparation of the ſalt, or conſtituted an attractive power counteracting the attraction of the ſalt to the water. It would have required a particular ſeries of experiments to aſcertain this as a fact; but ſeveral obſervations incline me to believe it is ſo; and the conſequences to be drawn from it would be ſufficiently curious, and applicable to many points of theory. Of the ſame nature, perhaps, is another circumſtance already hinted at, that after the ſolution has begun to form cryſtals of nitre, the depoſition proceeds with increaſed rapidity as the cooling goes on. This may, indeed, be owing to the attraction of the water to the ſalt decreaſing in a progreſſive ratio with each degree of cold; but it may alſo depend on the attracting ſurfaces being multiplied as more cryſtals are formed: and ſtirring the liquor ſeems to haſten the progreſs of the depoſition; which may be aſcribed to its bringing freſh portions of the ſolution perpetually to thoſe attracting ſurfaces; for, if there be ſuch an attraction, it can ſcarcely be ſuppoſed to take place at any ſenſible diſtance.

Upon the whole it ſeems evident from the preceding table, that the effect of nitre, like that of common ſalt, is to depreſs the freezing point in the ſimple ratio of its proportion to the water; which will be found univerſally true when allowance is made for the depoſition and other ſources of fallacy already enumerated.

This nitre produced, with ſnow, a cold of between 26° and 27°.

As nitre ſunk the freezing point of water ſo little, namely, but 6 degrees, I had recourſe for the next ſet of experiments to that neutral ſalt which, after ſea ſalt, produces the greateſt cold with ice; which is, the common ſal ammoniac. The different ſolutions of this ſalt in water, being ſubmitted to the action of the frigorific mixtures, froze according to the following table.

Sal ammoniac.

Proportion of water to the ſalt.	Freezing point by the experiment.	Freezing point by calculation.
	°	°
15,7 : 1	24½	24⅓
10 : 1	20½	20
9,8 : 1	20	19¾
7,9 : 1	16½	16¾
6 : 1	12	12
5 : 1	8	8
4 : 1	4	ſalt depoſited

The third column is calculated from the laſt experiment but one, in which the freezing point of a ſolution of one part of the ſal ammoniac in five of water proved to be 8°.

In this table alſo the numbers of the third colum agree ſufficiently with thoſe of the ſecond to ſhew, that ſal ammoniac, like the two preceding ſalts, depreſſes the freezing point in the ſimple ratio of the proportion in which it is mixed with the water.

The following is the account, as written at the time, of the experiment where the ſalt was to the water as 1 : 5. “ This “ ſolution cooled down to 2° at bottom, but the frigorific mix- “ ture being inſufficient, the top remained at 10°. The tum- “ bler was then taken out, and the frigorific mixture being “ refreſhed by ſtirring and the addition of new materials, it

" was replaced, when ice ſoon began to form at the bottom, " like feathered cryſtals, which however ſhot out very ſlowly. " But upon ſtirring the ſolution, a vaſt number of ſtellated " feathered cryſtals preſently formed in it, the thermometer " roſe immediately to 7°½, and was ſoon got to 8°." I have tranſcribed theſe remarks, not only becauſe they elucidate ſome of the phænomena mentioned in former experiments, but likewiſe on account of the ſtriking analogy the cryſtals bore to the configurations obſerved in a drop of the ſolution of this ſalt viewed with the microſcope. As the drop dries, great numbers of feathered cryſtals ſhoot out from its edges, and ſome more perfect ſtellated cryſtals are often formed in the middle; of which a pretty exact repreſentation may be ſeen in BAKER's Employment for the Microſcope (p. 110. Pl. II.). The reſemblance of both kinds of cryſtals, in theſe two different ſituations, is very great; and their particular figure is probably due to the ſame cauſe, a confuſed and conſtrained cryſtallization, occaſioned in the one caſe by the haſty evaporation and want of room in the drop, and in the other caſe by the watery congelation acting upon and embarraſſing the natural tendency of the ſalt.

A ſtronger ſolution of ſal ammoniac, the proportions being 1 : 4, exhibited a ſtill more beautiful appearance; for, beſide the feathered cryſtals at bottom, and the ſtars floating in the middle, a third ſort of cryſtals, moſt reſembling the ſtars, attached themſelves to the ſides of the tumbler, and were ſeen through the glaſs as compoſing a great variety of brilliant *facettes*. In this experiment the ſolution was reduced below 1°, before any congelation began to take place, and a certain quantity of the ſalt fell to the bottom in the form of a white powder, about as much as reduced the liquor to the ſtate of a ſaturated ſolution *at the freezing* point, which therefore, when the congelation took place, proved to be 4°, inſtead of 2°, the number that would have anſwered to this proportion of ſalt.

It has been a queſtion much conteſted, whether ſaline ſolutions depoſit their ſalt upon freezing. That ſome ſeparation, or a tendency to ſeparation, takes place, many facts concur to prove; and among the reſt ſome phænomena obſerved in the above-mentioned experiments. For inſtance, the ſtellated cryſtals, when firſt formed, were barely ſuſpended in the water, and ſometimes they even gradually ſubſided to the bottom; which ſhews, that they conſiſted of ſalt chiefly, only inviſcated with ice, or at leaſt of an over-proportion of ſalt: for the principal maſs of ice formed in a ſaturated ſolution floats in it like common ice in pure water. Beſides, it was almoſt conſtantly found, that when a cruſt of ice, which had been formed in a ſaline ſolution, began to thaw, a thermometer thruſt into it roſe ſomewhat higher than the point at which it had become ſtationary when the congelation took place; an indication that a leſs proportion of ſalt was preſent in it than had been in the whole ſolution. And if, after any ſolution had ſhot and formed a quantity of ice, the tumbler were ſtill kept in the frigorific mixture, the thermometer immerſed in the liquor gradually ſunk lower and lower, as the congelation proceeded. But theſe very obſervations ſhew, that the ſeparation is far from perfect; as the riſe of the thermometer in the former caſe, or its deſcent in the latter, never exceeded one or two degrees, under a great variation in the quantity of ice in the ſolution.

Sometimes in ſolutions of ſal ammoniac, and ſuch other ſalts as ſeparate by the cooling of the water, a ſort of flocculent ſubſtance is formed, which ſubſides in the water, and thereby is diſtinguiſhed from the proper ice of the ſolution, which it otherwiſe much reſembles in appearance. It is compoſed principally of the depoſited ſalt, in very minute cryſtals like powder, inviſcated and kept together with a little ice.

Though ſal ammoniac forms a tolerably tranſparent ſolution, yet I perceive that in theſe experiments it was in few inſtances cooled much below its freezing point; the moſt was nine degrees. I believe this to have been accidental, from no particular attention being now beſtowed on that object.

The ſal ammoniac, mixed with ſnow, produced a cold of from 4° to 4°½ of Fahrenheit's ſcale.

Of all the ſolutions ſubmitted to theſe experiments, there were none more tranſparent and elegant than thoſe made with Rochelle ſalt. The water diſſolved a large proportion of this ſubſtance, and had its freezing point ſunk according to the following table.

Rochelle ſalt.

Proportion of water to the ſalt.	Freezing point by the experiments.	Freezing point by calculation.
	°	°
10 : 1	29½	29¾
5 : 1	27½	27½
4 : 1	26⅓	26½
2,6 : 1	24	23½
2,25 : 1	22½	22¼
2 : 1	21	21
1,6 : 1	24	ſalt depoſited

The third column is calculated from the laſt experiment but one, in which the freezing point of a ſolution of one part of the Rochelle ſalt in two parts of water proved to be 21°.

All the ſolutions of Rochelle ſalt bore to be cooled remarkably well. In one inſtance the liquor ſunk 11½ degrees below its freezing point; namely, the ſolution of one part of the ſalt in five of water, whoſe freezing point proved 27°½, and which cooled to 16° before the cryſtals of ice ſhot. In two other inſtances it ſunk fully nine degrees below its freezing point. And, as already has been mentioned, the ſolutions of this ſalt are remarkably tranſparent.

In trying the greateſt cold to be obtained by mixing Rochelle ſalt with ſnow, I could get the thermometer no lower than 24°.

GLAUBER's ſalt likewiſe was ſubjected to the experiments, but its utmoſt effect in producing cold with ſnow appearing to be only two degrees, this was too ſmall a ſcale for ſettling any thing as to the ratio. A ſolution of it in water, in the proportion of 1 : 5, cooled readily to 31°; but the ſalt was depoſited in great quantities, and often ſo faſt, as to ſtop the cooling of the bottom of the liquor entirely, though the veſſel was immerſed in a ſtrong frigorific mixture. This phænomenon has been obſerved before; but does not take place, to the ſame degree, in the ſolutions of any other ſalt with which I am acquainted, though I evidently perceived ſomething of it in the ſtrong ſolutions both of nitre and of ſal ammoniac. It is exactly the converſe of the cold produced by diſſolving ſalts in water; for as there ſome heat is abſorbed, and becomes latent, by the change of the ſalt from a ſolid to a fluid ſtate, ſo here ſome heat is evolved as the ſalt aſſumes the ſolid cryſtalline form. The effect is ſo much more manifeſt with GLAUBER's ſalt only, I imagine, becauſe the formation of the cryſtals proceeds ſo rapidly; whence the quantity of heat generated equals or exceeds the cold communicated by the freezing mixture. Some odd appearances are produced by this ſudden ſtop of the cooling, and the rapid depoſition of ſalt; for inſtance, a particular ebullition in certain parts of the liquor; but any intelligible deſcription of them would be too minute.

Theſe were all the ſalts with an alkaline baſis which I tried. They all agreed as to the chief object of theſe experiments, namely, to determine how much the freezing point of water would be ſunk by diſſolving them in it in various proportions; which by theſe experiments appears to be, as nearly as could be determined, according to the ſimple ratio of the proportion each ſalt bears to the water.

I now reſolved to try a few ſalts with an earthy and metallic baſis.

The common ſal catharticus amarus of the ſhops was the ſpecimen I uſed of an earthy ſalt. It formed a turbid inelegant ſolution, as if dirty; and with various proportions of water produced the following points of congelation.

Sal catharticus amarus.

Proportion of water to the ſalt.	Freezing point by the experiment.	Freezing point by calculation.
16 : 1	31°	31°
10 : 1	30	30½
4 : 1	28¼	28
3 : 1	26⅘	26⅘
2,4 : 1	25½	25½

The third column is calculated from the laſt experiment, where the freezing point of a ſolution of one part of the ſal catharticus amarus in 2,4 of water proved to be 25°½.

No ſalt was depoſited from the ſtrongeſt of theſe ſolutions; and as that which I uſed was a deliqueſcent ſalt, it muſt probably have been in a vaſt proportion to the water, before any ſuch effect would have taken place. I have ſunk a thermometer with it and ſnow to 7°½; which, according to the proportions in the table, would make more than three parts of the ſalt to two of water. Accordingly, a large quantity of the ſalt was required to the ſnow.

No particular phænomenon was obſerved with this ſalt, except the ſingular configuration of its ice, which aſſumed the form of fungi, or of ſome kinds of lichen, with feathered ſtriæ. The ſolutions were difficult to cool much below their freezing point.

Of the ſalts with a metallic baſis, green vitriol affords one of the moſt tranſparent ſolutions in water. It ſinks the thermometer nearly to 27°½ with ſnow, and reduced the freezing point of water according to the following table.

Green vitriol.

Proportion of water to the ſalt.	Freezing point by the experiment.	Freezing point by calculation.	
	°	°	The third column is calculated from the laſt experiment, in which the freezing point of a ſolution of one part of the green vitriol in 2,4 of water proved to be 28°.
10 : 1	30¾	31	
6 : 1	30¼	30½	
4 : 1	29¾	29½	
3 : 1	28¾	28¾	
2,4 : 1	28	28	

The ice formed by theſe ſolutions aſſumed a foliaceous configuration, with a texture of penniform ſtriæ, in ſome reſpects like the appearance exhibited by a drop evaporating under a microſcope, as delineated by BAKER. Scarcely any ſalt gave the point of congelation ſo regularly in the proportion of the quantities mixed with the water, and none afforded ſolutions which cooled more eaſily and readily below the freezing point. In two inſtances the cooling was more than 11 degrees.

Having found that white vitriol, mixed with ſnow, produced a cold of 20°, melting the ſnow remarkably faſt, I was induced to try the freezing point of its ſolutions. But though it diſſolved very readily in water, yet the liquor it formed was ſo turbid and thick, that little ſatisfaction could be derived from the experiments. The only numbers to be relied upon are the following, which agree ſufficiently with the general reſult.

White vitriol.

Proportion of water to the ſalt.	Freezing point by the experiment.	Freezing point by calculation.
	°	°
10 : 1	31	31
5 : 1	$29\frac{1}{2}$	30
3 : 1	$28\frac{2}{3}$	$28\frac{2}{3}$

The third column is calculated from the laſt experiment, in which the freezing point of a ſolution of one part of the white vitriol in three of water proved to be 28°$\frac{2}{3}$.

Theſe ſolutions cooled very ill, none of them having ſunk much below the freezing point, and the ſtrongeſt, which had a copious ſediment, forming a cruſt of ice at the bottom of the tumbler, before it was reduced at all below the term of congelation.

M. Achard, of Berlin, having alledged*, that borax inſtead of raiſing the boiling point of water, like other ſaline ſubſtances, very ſenſibly depreſſes it, I determined, however extraordinary the fact might appear, to try whether it had any peculiar effect on the freezing point. But having made the experiment with nearly a ſaturated ſolution of borax, the thermometer when it congealed was evidently below 32°: I believe about a degree.

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* See Crell's Chem. Annalen, 1786, Vol I. p. 501.

As a neutral or middle ſalt, which when cryſtallized is always nearly of the ſame nature, and diſſolves in a regular proportion in water, ſeemed likely to afford the moſt ſimple caſ of the effect of extraneous admixtures, it was with ſuch tha I began theſe experiments. But having found that with them the ſimple ratio prevailed, I proceeded to try ſubſtances of a more variable nature, and capable of being mixed with water in almoſt any proportion; ſuch as acids, alkalies, and ardent ſpirits. A material difference in the law, which ſeemed to occur in theſe new experiments, renders it proper to defer the account of them till ſome reflections on the preceding facts, with a few additional experiments to which they gave riſe, have been premiſed.

It is now, I believe, univerſally allowed, that in frigorific mixtures the melting of the ſnow or ice is the principal cauſ of the cold produced; all that heat which muſt become laten in order to give water its fluid form being taken from the ſenſible heat of the ingredients. But as, when cryſtallized ſalts are employed for the purpoſe, theſe alſo are reduced to a liquid form, there muſt, from this circumſtance, be ſome additional cold produced, ſuch for inſtance as would be occaſioned by diſſolving the ſame ſalt in water. Suppoſe then that the latent heat of water is 150 degrees, and that ſal ammoniac, in diſſolving to ſaturation, produces ſo much cold as ſinks the whole ſolution about 20°; it is evident, that if this ſalt and ice are mixed together in ſuch proportions as juſt to melt one another, the total cold generated in the operation muſt amount to 170 degrees.

And ſo much actually is produced before the whole liquefaction is effected; and yet a mixture of theſe two ſubſtances will ſink the thermometer no lower than to 4° of FAHRENHEIT's ſcale. The conſideration of this apparent difficulty has led to the ſuppoſition, that a certain quantity of *fire* is contained in the cryſtals of the ſalt, which being diſengaged in the ſolution keeps up the mixture to a certain temperature *. But I conceive, that the phænomenon depends ſimply on the gradual liquefaction of the ingredients, a neceſſary conſequence of the cold produced. A ſaturated ſolution of ſal ammoniac freezes itſelf at 4°; therefore, when the mixture is reduced, by the liquefaction of the ingredients, to that temperature, no more of them can melt, becauſe any addition of cold would freeze what is already melted; and if the mixture, under ſuch circumſtances, were placed in an atmoſphere of its own temperature, the ingredients would remain for ever in that ſame ſtate, without any further liquefaction. But in an atmoſphere warmer than 4°, they continue to melt, more or leſs ſlowly, as the heat which is gradually communicated furniſhes what is neceſſary to become latent. This communicated ſenſible heat being immediately converted into latent, the mixture will always be kept down to the ſame temperature as long as there is a ſufficient maſs of unmelted materials; and it can ſink no lower, becauſe then the liquefaction would be ſtopped; conſequently ſuch mixtures muſt preſerve, as they have been found to do, a pretty uniform temperature, ſo as to have been formerly uſed for graduating thermometers. And the whole cold produced, or, to ſpeak properly, the whole of the heat made to diſappear, I preſume to be ultimately equal to the full quantity of latent heat belonging to the diſſolved ice and ſalt.

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* DE LUC's Idées ſur la Météorologie, Tom. I. p. 201.

According to this explanation, the greateſt cold to be produced with any ſalt and ice or ſnow ſhould be that with which a ſaturated ſolution of the ſame ſalt freezes; which was formerly eſtabliſhed by M. DE LUC as a fact, and is in general conformable to the preceding experiments. Thus, when a ſolution of one part of ſal ammoniac in four parts of water was put into the frigorific mixture, ſome of the ſalt was depoſited, and then the ſolution on freezing raiſed the thermometer to 4°, which is exactly the cold produced by a mixture of the ſame ſalt with ſnow. Likewiſe the ſtronger ſolutions of nitre had their freezing point between 26° and 27°; thoſe of green vitriol near 28°; and ſo of moſt of the other ſalts, correſponding with the cold of their frigorific mixtures. This agreement, however, is liable to be modified by ſeveral circumſtances. For inſtance, if the ſalt be of that nature that more of it is held in ſolution in warm than in cold water, it becomes extremely difficult to have the ſolution, at the moment it freezes, exactly loaded with that quantity of ſalt which is moſt advantageous for acting upon the ice or ſnow. Too much may have been depoſited by the cooling previous to the congelation; or ſome reſiſtance having occurred to the cryſtallization of the ſalt, more of it may be retained at the moment of congelation than properly belongs to the ſolution at that temperature. The purity of the ſalts likewiſe, their particular nature as inclined to deliqueſce or to fall down in powder in the air, the rapidity of their action upon the ice or ſnow, muſt neceſſarily be taken into the account, as influencing the degree of cold they can produce.

It is an evident corollary from the above-mentioned agreement, that if the freezing point of the ſolution of a ſalt in water in any known proportion be given, its degree of ſolubility may in general be aſcertained, merely by trying the greateſt cold it will produce with ſnow.

Notwithſtanding this uſual correſpondence between the greateſt quantity of a ſalt that could be diſſolved, and the greateſt degree of cold it would produce, compared with the freezing point of its ſolution, I ſaw reaſon to believe that, with ſome ſalts at leaſt, an irregularity took place in this reſpect. The Rochelle ſalt, mixed with ſnow, did not ſink the thermometer lower than 24°; yet the freezing point of a ſolution of one part of it in two of water appears, by the numbers in the table, to have been 21°. It is remarkable, however, that in the experiment with a ſtill ſtronger ſolution, where ſome of the ſalt was depoſited, the freezing point came down to 24°. Likewiſe the ſolution of white vitriol, whoſe freezing point was 28°$\frac{2}{3}$, depoſited a copious ſediment, and yet produced with ſnow a cold of 20°. This ſediment did not look like cryſtallized ſalt, but gave a turbid appearance to the whole ſolution. The moſt remarkable circumſtance of this nature, I think, occurred with the purified common ſalt; which, when mixed with ſnow, ſunk the thermometer only to − 4°. By experiment I found that one part of this ſalt would diſſolve in about 2°$\frac{1}{2}$ of water. Now, if the proportions of 1 to 4 give the freezing point at + 4°, as by the table; 1 to 2$\frac{1}{2}$ would, upon the general analogy, give it between − 12° and − 13°; that is, 8 or 9 degrees lower than the greateſt cold the ſalt would produce with ſnow. This circumſtance leads to a ſuſpicion, that however uniform the preceding tables appear, yet in reality ſomething of a decreaſing ratio exiſts, and that each ſubſequent addition of a ſalt does not depreſs the freezing point quite ſo much as the preceding. In thoſe ſalts where the whole quantity of depreſſion is but ſmall, and in the upper part of the ſcale in thoſe which have a greater effect, this progreſſion may be inſenſible, or be incapable of determination by ſuch experiments as theſe, which by their nature do not admit of extreme accuracy; but it may become ſufficiently obſervable toward the laſt additions of ſuch ſalts as are ſoluble in great quantity, and ſuch as alter very much the freezing point. I never ſucceeded to freeze the ſaturated ſolution of this Borrowſtounneſs common ſalt, though it has been cooled ſeveral degrees below – 4° without depoſiting any of its ſalt; if the experiment were made in a cold ſufficient for the purpoſe, it would ſhew whether any irregularity takes place in the action of this ſalt upon ſnow, or whether ſuch a decreaſing ratio does exiſt. Perhaps, however, the whole may depend upon the principle alluded to formerly, that the preſence of ſome ſalt favours the depoſition of more: for when a ſalt is mixed with ſnow, it may in this point of view be conſidered as in the ſame ſtate with a ſaturated ſolution of the ſalt which has ſome of it remaining undiſſolved; and which, therefore, will not contain more than properly belongs to it at the given temperature; and the cold of ſuch a frigorific mixture ſhould be no greater than that of the freezing point of the ſaturated ſolution under thoſe circumſtances.

As it is well known that water, after it has been ſaturated with one ſalt, will take up a certain portion of another ſalt without depoſiting any of the former, I was curious to try what effect the addition of this ſecond ſalt would produce on the freezing point; and particularly whether it would depreſs the freezing point of the ſaturated ſolution the ſame number of degrees that an equal proportion of the ſame ſalt would depreſs the freezing point of water; and whether the ſame ſimple ratio would hold good, or any new law take place. To bring this to the teſt of experiment, I took a ſaturated ſolution of nitre, whoſe freezing point of courſe was between 26° and 27°: and adding to it the purified common ſalt in various proportions, I obtained the following reſults.

Compound ſolution of nitre and common ſalt.

Proportion of water to the nitre.	Proportion of water to the common ſalt.	Freezing point by the experiment.	Freezing point by calculation.	Difference.
		°	°	°
A ſaturated ſolution.	30,2 : 1	23½	22¾	¾
	15 : 1	20¾	19	1¾
	10 : 1	17½	15¼	2¼
	7,4 : 1	13½	11½	2
	5 : 1	5¼	4	1¼

The ſolution of nitre was one that had been made ſome time, and contained near one-ſixth part of nitre, conſequently more than the water could keep diſſolved in the temperature of the atmoſphere, which was then not much above 40°. Some of it therefore was depoſited at the bottom. This, however, the addition of a $\frac{1}{32}$ part of common ſalt ſoon enabled the water to take up, and the two ſalts formed together a clear ſolution. In the frigorific mixture, before the congelation took place, ſome ſaline cryſtals were again depoſited, which ſeemed to be chiefly, if not entirely, nitre. In the temperature of the air this depoſit was re-diſſolved; and on attending to the circumſtances more carefully, upon a repetition of the cooling, I found, that no ſalt began to be depoſited till the ſolution was reduced to 23°, when ſome needle-like cryſtals appeared, which conſequently were nitre. The ſolution cooled about a degree more, and then, having let fall much ſalt, partly as cryſtals and partly, by ſtirring, as a powder, it was made to congeal by dropping in a bit of ſnow, and the thermometer roſe to 23°½. When more ſalt was added, to render its proportion to the water as 1 : 15, the nitre ſeemed ſtill more difficultly depoſited in the freezing mixture; and this continued to be the effect of further additions of ſalt, the depoſition of ſaline matter previous to the congelation being always leſs, in proportion as the quantity of common ſalt was greater.

It is evident from the freezing points of this compound ſolution, that the common ſalt depreſſed the freezing point of the ſolution of nitre ſomething leſs than it would have depreſſed the freezing point of water, if added to it in the ſame proportion. To ſhew this more evidently, I have added a fourth and a fifth column to the table: the fourth column is formed by taking the freezing point of the ſaturated ſolution of nitre as 26°½, and then finding how many degrees the quantity of common ſalt added would have depreſſed the freezing point of water; this number of degrees, ſubtracted from the conſtant number 26°½, gives the freezing point by calculation; namely, what it ſhould have been if the ſalt had produced the ſame effect upon the ſolution of nitre as it would upon pure water; and the difference between this and the freezing point found by the experiment gives the numbers in the fifth column. From the table it is apparent, that the deficiency of effect from the ſalt goes on increaſing to the third experiment, after which it decreaſes. Probably ſome particular law takes place, which it would require a great number of experiments to develope; but the decreaſe toward the laſt may in part be owing to the greater quantity of nitre which the water, when it began to be loaded with common ſalt, retained at the time of congelation, and which muſt have its effect in depreſſing the freezing point. The above-mentioned circumſtance ſeems rather contradictory to an opinion which has been entertained, that when one ſalt, added to a ſaturated ſolution of another ſalt, enables it to take up more of the former ſalt, it is only becauſe the water of cryſtallization of the ſecond ſalt really adds to the quantity of the diſſolving fluid.

I next proceeded to try a ſimilar experiment with ſal ammoniac and the purified common ſalt, but with this difference, that neither ſalt ſhould be added to the water in ſuch quantity as to come near the point of ſaturation, ſuſpecting that the diminution of effect obſerved in the foregoing experiments might depend, in part at leaſt, upon this circumſtance. The ſal ammoniac, therefore, was diſſolved in water in the proportion of 1 : 10, and the correſponding point of congelation appeared by experiment to be 20°½, agreeing very well with the table of ſal ammoniac formerly given. To this ſolution was added the purified common ſalt, in proportion to the water as 1 : 15, and then as 1 : 10; the reſulting points of congelation were as is ſhewn in the following table, conſtructed in all reſpects as the immediately preceding.

Compound ſolution of ſal ammoniac and common ſalt.

Proportion of water to the ſal ammoniac.	Proportion of water to the common ſalt.	Freezing point by the experiment.	Freezing point by calculation.	Difference.
10 : 1	15 : 1	12°¾	13°	+ ¼
10 : 1	10 : 1	9¼	9⅕	− 1/20

Hence it appears, that in this compound ſolution both ſalts produced, as exactly as the experiments can be expected to ſhew, their full effect in depreſſing the point of congelation. When the ſolutions at length froze, after cooling many degrees below the freezing point, the cryſtals ſhot in a very beautiful manner round the bulb and up the ſtem of the thermometer.

In a compound ſolution of Rochelle and common ſalt there was, however, a deficiency of effect. For the ſolution of Rochelle ſalt in the proportion of one part to four of water, having its freezing point at $26^{\circ}\frac{1}{3}$; when common ſalt was diſſolved in it, in the proportion of $\frac{1}{10}$th, the freezing point appeared by experiment to be $16^{\circ}\frac{1}{4}$, whereas by calculation it ſhould have been depreſſed nearly to 15°.

A compoſition of three ſalts was affected as follows:

Compound ſolution of Rochelle ſalt, common ſalt, and ſal ammoniac.

Proportion of water to the Rochelle ſalt.	Proportion of water to the common ſalt.	Proportion of water to the ſal ammoniac.	Freezing point by the experiment.	Freezing point by calculation.	Difference.
9,8 : 1	10 : 1	17 : 1	13° −	$11\frac{1}{2}^{\circ}$	$-1\frac{1}{2}^{\circ}$

The computation is made thus: Rochelle ſalt, in the proportion of 1 : 9,8, depreſſes the freezing point $2^{\circ}\frac{1}{4}$; common ſalt, in the proportion of 1 : 10, ſinks it $11^{\circ}\frac{1}{4}$; and ſal ammoniac, in the proportion of 1 : 17, ſinks it 7°; now $2\frac{1}{4} + 11\frac{1}{4} + 7 = 20\frac{1}{2}$; which, ſubtracted from 32, leaves $11^{\circ}\frac{1}{2}$ for the computed freezing point of this mixture.

The moment I had found by experiment that the addition of a different ſalt to the ſaturated ſolution of any ſalt would ſtill further depreſs its freezing point, it was obvious to conclude, that greater cold could be produced with ſnow by a mixture of ſalts than by means of either taken ſeparately. I made ſeveral experiments with this view, and found it uniformly the fact, that by adding a certain proportion of a ſalt which had leſs power of producing cold with ſnow, to one which had a greater power, the frigorific effect of the latter was ſenſibly increaſed. Paſſing over examples of leſs conſequence, it will be ſufficient to inſtance common ſalt and ſal ammoniac. The ordinary common ſalt I uſed to mix with ſnow, ſunk the thermometer to − 5°; the ſal ammoniac to + 4°; but when ſome of the latter ſalt was mixed with the former, the compoſition produced with ſnow a cold of − 12°. I did not carry the experiments far enough to determine the proportions which anſwered beſt, but ſaw evidently, that a conſiderable variety in this reſpect occaſioned ſcarcely a perceptible difference: more ſal ammoniac was, however, required, than that proportion of it to the common ſalt, which ought, by computation, to have ſunk a ſaturated ſolution of the latter 7 degrees. On ſeveral occaſions I made uſe of this compoſition to obtain a greater degree of cold than common ſalt alone would produce, and found it a very convenient method.

On this principle it is that impure common ſalt always makes a ſtronger freezing mixture than the pure; it being, in fact, a compoſition of ſalts. I have ſeen three ſalts produce a greater cold than two, but have not carried the experiments far enough to aſcertain the limits of this effect *.

M.

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* The curious experiments, related in the Philoſophical Tranſactions for 1787, p. 282. of producing a great degree of cold by diſſolving a mixture of ſalts in water, depend in part upon the ſame principle, the water being capable of reducing more ſalt from a ſolid to a fluid ſtate when ſeveral kinds are employed,

M. DE REAUMUR propoſed to try what cold gunpowder would produce with ſnow, as a teſt of its goodneſs, that is, of the purity of the nitre in its compoſition. It is evident, from what has been delivered above, that if any ſaline impurity be mixed with the nitre, a frigorific mixture formed with the compoſition will be lower than 26°½, a greater or leſs number of degrees, according to the nature and quantity of the impurity; and if it be only common ſalt, the proportion of it to the nitre may be thus determined pretty nearly.

As the cold produced by common ſalt with ſnow is −4° or more, and by ſal ammoniac +4°, it is difficult to conceive in what manner FAHRENHEIT fixed the zero of his thermometer. All thoſe who have examined the few authentic paſſages to be found in authors upon this ſubject, will be ſenſible how vaguely they are expreſſed, leaving it doubtful whether he uſed common ſalt alone, ſal ammoniac alone, or both mixed together. There is no method of ſinking a thermometer exactly to 0° with theſe ſalts and ſnow, but by means of a certain ſmaller proportion of common ſalt added to the ſal ammoniac; and it would have been an extraordinary chance, that FAHRENHEIT ſhould hit preciſely this proportion often enough to make him rely upon the point ſo found as the commencement of his ſcale; more eſpecially as the proportion

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employed, than it could of one of the kinds only. A remarkable fact of this nature, as I imagine, is recorded ſo early as in the Memoirs of the French Academy of Sciences for 1700, p. 116. "On prend une livre de ſublimé corroſif, et une "livre de ſel ammoniac; on les pulveriſe chacun à part; on mêle enſuite les "deux poudres très exactement; on met le melange dans un matras, verſant "par-deſſus trois chopines de vinaigre diſtillé; on agite bien le tout: et ce me-"lange ſe refroidit ſi fort, qu'on a peine à tenir long-tems le vaiſſeau dans les "mains en été. Il eſt arrivé même quelque fois à M. HOMBERG, que faiſant ce "melange en grande quantité, la matière s'eſt gelé."

is probably no greater than a ſeventh or a ſixth of common ſalt to the ſal ammoniac. Is it poſſible that FAHRENHEIT, finding a conſiderable difference in his experiments, took the mean between them for his zero, without any reſpect to the different nature of the ſalts with which he operated? It appears, that he was at this time ſo little acquainted with the ſubject, as to conſider his zero as the utmoſt limit of cold.

I come now to certain ſubſtances which, by equal additions, ſeem to depreſs the freezing point of water in an *increaſing ratio.* Theſe, as was mentioned before, are acids, alkalies, and ſpirit of wine. I judge this to be the caſe from the following experiments, though they are by no means ſo full and extenſive as I could have wiſhed to make them, had leiſure permitted.

The ſpecific gravity of the vitriolic acid I employed was 1,837 at 62° of heat; its effect upon the freezing point is ſhewn by the following table.

Vitriolic acid.

Proportion of water to acid.	Freezing point by the experiment.	Freezing point by calculation.
	°	°
10 : 1	24½	22¼
5 : 1	12½	12⅔
4 : 1	7½	7½

This table is conſtructed in the ſame manner as thoſe formerly given of the ſolution of ſimple ſalts; the laſt experiment, where the proportion is 4 : 1, being taken as the ſtandard for computation; and the extreme difference between the calculation and experiment is no leſs than 2°¼, upon a reduction of the freezing point from 24°½ to 7°½. The freezing point, ſet down in the table, is that to which the liquor roſe upon congealing, after having been cooled ſeveral degrees lower; which it is proper to remark, becauſe the ice roſe two or three degrees in thawing.

The nitrous acid I employed was ſmoaking, and had its ſpecific gravity 1,454. It acted on the freezing point according to the following table, which is conſtructed in all reſpects like the preceding.

Proportion of water to acid.	Freezing point by experiment.	Freezing point by calculation.
	°	°
16,8 : 1	26⅓	25⅔
10 : 1	22 −	21½
7,64 : 1	18	18
5,06 : 1	10½	11
4,26 : 1	7	7

The greateſt difference between the calculation and experiment appears here to be only two-thirds of a degree; but that is more than, I think, can be attributed to inaccuracy. Theſe mixtures cooled remarkably well; that in which the water was to the acid as 7,64 : 1 ſunk down to 6° before it froze. The ice heated about a degree before it was melted.

Spirit of ſalt being a very weak acid, its increaſe of ratio was not perceptible within the limits to which I was confined.

Muriatic acid.

Proportion of water to acid.	Freezing point by experiment.	Freezing point by calculation.
	°	°
10 : 1	25	25
5,1 : 1	18$\frac{4}{5}$	18$\frac{1}{2}$
3,05 : 1	9$\frac{1}{3}$	9$\frac{1}{3}$

This table is conſtructed as the foregoing; and the ſpecific gravity of the marine acid was 1,163.

Salt of tartar, ſuch as is uſually ſold in the ſhops, was the vegetable alkali I employed. It did not readily deliqueſce, and conſequently was not very cauſtic: the cold it produced with ſnow was − 12°.

Salt of tartar.

Proportion of water to alkali.	Freezing point by experiment.	Freezing point by calculation.
	°	°
10 : 1	27$\frac{1}{4}$	26$\frac{1}{2}$
7,5 : 1	25$\frac{1}{2}$	24$\frac{4}{5}$
5 : 1	22$\frac{3}{4}$	21$\frac{1}{5}$
3 : 1	15	14
2,5 : 1	11$\frac{3}{4}$	10$\frac{1}{2}$
2 : 1	5	5

Here the greateſt difference between the calculation and experiment is ſomething more than 1$\frac{1}{2}$ degree, in ſinking the freezing point from 22°$\frac{3}{4}$ to 5°; but in the higher freezing points of the table it is leſs, as well as in the lower. Perhaps this irregularity in the experiments is in part to be aſcribed to an impurity in the ſalt of tartar; a turbid appearance, and at length a depoſition, took place in all theſe ſolutions, but principally in the ſtronger, occaſioned probably by tartar of vitriol, with which that ſalt is ſo frequently mixed.

The mineral alkali I tried, which was the cryſtallized ſoda of the ſhops, ſhewed no increaſe of ratio; but the ſcale of its operation was too ſmall for a proper judgement to be formed.

Mineral Alkali.

Proportion of water to alkali.	Freezing point by experiment.	Freezing point by calculation.
10 : 1	30° −	$29^\circ\frac{9}{10}$
5 : 1	$27\frac{4}{5}$	$27\frac{4}{5}$

This ſalt would not remain ſuſpended in much greater proportion in the cooled water. I conſider the ſolutions as decreaſing in their freezing point by an equal ratio: poſſibly, if the ſalt of tartar had been cryſtallized, and perfectly ſaturated with fixed air, it would alſo have acted in the manner of a neutral ſalt, and produced no increaſe upon the ratio.

My volatile alkali, being the ſal volatilis ſalis ammoniaci, was tried only in two proportions.

Volatile alkali.

Proportion of water to alkali.	Freezing point by experiment.	Freezing point by calculation.
	°	°
10 : 1	25	25¼
5,18 : 1	19	19

Here alſo there is no appearance of an increaſe of ratio, but rather the contrary.

The ſpecific gravity of the ſpirit of wine I employed was ,829 at 62°. It depreſſed the freezing point according to the following table.

Spirit of wine.

Proportion of water to ſpirit.	Freezing point by experiment.	Freezing point by calculation.
	°	°
8,5 : 1	24½	23¾
5 : 1	17	18
3,66 : 1	12¼	12¾
3 : 1	8½	8⅔
2,5 : 1	4	4

The total difference between the calculation and experiment, upon a reduction of the freezing point from 24°½ to 4°, is ¾ of a degree; but the intermediate points are very irregular, and in an oppoſite ſenſe, as if the ratio were decreaſing. It ſeems more probable, that ſome inaccuracy in the experiments, perhaps owing in part to the evaporation of the ſpirits, ſhould be the occaſion of this, than that there ſhould be ſuch an irregularity in the law.

If any perſon ſhould alledge, that the difference between the obſerved and computed freezing points in the foregoing tables is not ſufficient to eſtabliſh the increaſe of ratio, I can only reply, that it appears to me greater than can reaſonably be aſcribed to error in the experiment; eſpecially as ſimilar experiments with neutral ſalts, not conducted more attentively, agreed ſo well together in pointing out a different law. It muſt be allowed, however, that the experiments do not ſhew any increaſe of ratio, except in the vitriolic and nitrous acids, ſalt of tartar, and, with more ambiguity, in ſpirit of wine: from analogy only I ſuſpect it to take place in the other acids, and in the mineral and volatile alkalies provided they are cauſtic. That a different law from what prevails in the neutral ſalts ſhould take place with theſe ſubſtances, ſeems not ſurpriſing, when it is conſidered how much ſtronger attraction they ſhew for water, and how much leſs limited the proportion is in which they will unite to it: for the ſame reaſons, I ſhould not think it extraordinary, if deliqueſcent ſalts, combined with water, ſhould be found to obſerve the ſame increaſing ratio in depreſſing the freezing point.

As other experiments upon the watery congelation of acids, and in lower degrees of cold, have been given to the public, it would have been deſirable to compare them with mine, and thus to have obtained a greater length of ſcale. But the difficulty of aſcertaining the preciſe ſtrength of different acids is ſo great, and a ſmall uncertainty in this reſpect may occaſion ſo much error, that I conceive little reliance can be placed, with regard to the preſent object, upon any experiments except ſuch as are made by diluting the *ſame* acid with different proportions of water.

I ſhall conclude this Paper with the account of an experiment to determine the effect of ſalt upon the expanſion of water by cold. Pure water begins to ſhew this expanſion about the temperature of 40°, that is, 8 degrees above its freezing point. I put a ſolution of common ſalt, in the proportions of 4,8 parts of water to one of the ſalt, and conſequently whoſe freezing point was 8°$\frac{2}{3}$, into an apparatus I had uſed for other experiments of the ſame kind; and found that the ſolution continued to contract till it was cooled to 17°, but had ſenſibly expanded by the time it was cooled to 15°. Suppoſe the expanſion to have begun at 16°$\frac{2}{3}$, it would be juſt 8 degrees above its new freezing point. Hence we have reaſon to conclude, as far as one experiment goes, that the combination of a ſalt with water has no other effect upon its quality of expanding by cold, than to depreſs the point at which that quality begins to be ſenſible, juſt as much as it depreſſes the point of congelation.

It is probable, that the ſubject of this Paper will appear to ſome minute and trifling. Did it lead to nothing further, that opinion might be juſt. But it is by the accumulation of facts of this kind, and eſpecially ſuch as have been developed by Mr. CAVENDISH in his excellent Papers on the freezing of acids *, that the foundation muſt be laid for a general theory of the laws of coheſion, which may ultimately lead to a knowledge of the ſtructure upon which the intimate properties of bodies depend; in the ſame manner as more accurate obſervations of the different motions of the great maſſes in the univerſe, paved the way to the ſublime diſcoveries of KEPLER and NEWTON.

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* Philoſophical Tranſactions, Vol. LXXVI. p. 241. and p. 166. of this Volume.